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Power Quality Enhancement by Unified Power Quality Conditioner (UPQC) using P-Q Theory

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Abstract - In these days the power quality related problem become more severe due to the power electronics devices. Passive filters are not able tocompensate the power quality problems. UPQC (Unified power quality conditioner) is a device which can compensate the current and voltage related problem simultaneously. In this paper two control technique is explained to compensate the voltage sag, swell, harmonics, interruption and harmonic compensation.

***Keywords* - UPQC, Power Quality, Simulation, Voltage Sag, Voltage Swell, Voltage Harmonics, Current Harmonics.**

1. Introduction

In these days the use of non -linear devices has been escalated in the transmission and distribution system. These devices introduce non- linearity in the system, which causes the power quality problems in the system like voltage sag, swell, short interruption and long interruption. For the mitigation of these current and voltage based problems, we can remove that using CPD (custom power devices). With the advent of the FACTS devices the scenario of the power system has been changed in dramatic manner. In the present scenario our power system is very limited, there is very little space for the new devices installation to increase the capacity of the power system. So we need that type of mechanism which improve the present power system, enhance the power transfer capability of the system and make system more reliable. FACTS devices can do such things, they also helps to improve the power quality of the system. Different power electronics devices (FACTS devices) like DVR, STATCOM and UPQC are registered for the enrichment of power quality problems like voltage sag/swell etc. effectively.

The UPQC is a combination of series active filter and shunt active filter both are connected through the common DC link. Shunt active filter connected parallel to the transmission line. It is operate to compensate the load side current so that there would be no harmonics in source current. Series active filter connected in series to the transmission line. It is used to mitigate the voltage sag, swell and interruption from the source side so the load side voltage remain free from the problems. Controlling methods is a very important part for the UPQC. Control algorithm decides the efficiency and the operation of the UPQC. Earlier days there are many passive filter is used for the compensation for harmonics and transients but due there limitation and disadvantage they find very little space for work. The active filter now days are become popular. UPQC consists shunt current source inverter and voltage source inverter.

In this paper two control techniques is used for series and shunt filter and simulated in SIMULINK/MATLAB R2012a.

2. Control Algorithm for the UPQC

Here we shown a detailed configuration of UPQC in the Fig.1. Which consists two converters one is the series VSI and another is shunt VSI.

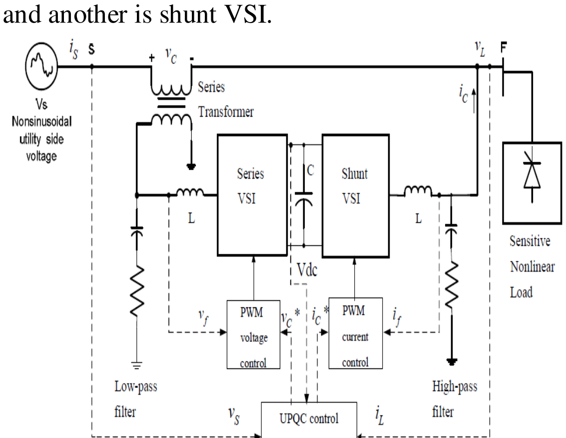

Fig. 1 Detailed configuration of UPQC

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Series inverter connected through the transformer to line and shunt inverter connected to the PCC (point of common coupling). There are two control block one for the controlling the series filter and other for the control the shunt filter. This UPQC connected with the nonlinear load which inject the harmonics in the system.

3. Control Algorithm for The Series Filter

A simple algorithm is developed to control the series filters. The control strategy is based on the extraction of Unit Vector Templates (UVT) from the distorted supply.The control strategy for the series APF is shown in Fig. 3.10. Since the supply voltage is unbalanced and or distorted, a phase locked loop (PLL) is used to achieve synchronization with the supply. Three phase distorted/unbalanced supply voltages are sensed and given to the PLL which generates angle (ωt) varying between 0 and $2*\pi$ radian, synchronized on zero crossings of the fundamental (positive-sequence) of phase A.

The sensed supply voltage is multiplied with a suitable value of gain before being given as an input to the PLL. The angle (ωt) output from the PLL is used to compute the supply in phase, 120° displaced three unit vectors (U_a ,U_b , U_c). The computed three in-phase unit vectors are then multiplied with the desired peak value of the PCC phase voltageV_{LM}^* which becomes the three-phase reference load voltages as from equation(1).

$$\begin{bmatrix} V_{La}^* \\ V_{Lb}^* \\ V_{Lc}^* \end{bmatrix} = [V_{Lm}^*] \begin{bmatrix} V_{La} \\ V_{Lb} \\ V_{Lc} \end{bmatrix} \qquad (1)$$

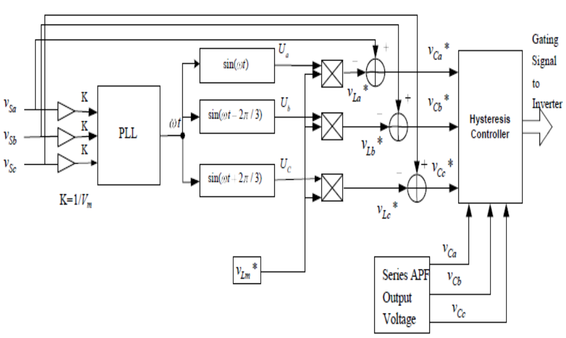

Fig. 2 Control Algorithm for The Series Filter

In order to have the sinusoidal voltage at the load so the sensed voltage at the load terminal should be equal to the reference voltage. The reference voltage is compared with the distorted supply for generating the compensating voltage and given to the hysteresis controller along with the sensed series filter output voltage. Hysteresis controller generate the switching signal for the inverter so that the load side voltage remain sinusoidal.

4. Control Algorithm for The Shunt Filter

The instantaneous reactive power (p-q) theory is used to generate reference signal for shunt APF. The control block diagram of shunt active filter is given in Fig.1. In this theory, the instantaneous three-phase currents and voltages are transformed to -ß-0 coordinates as shown in equation (2) and (3).

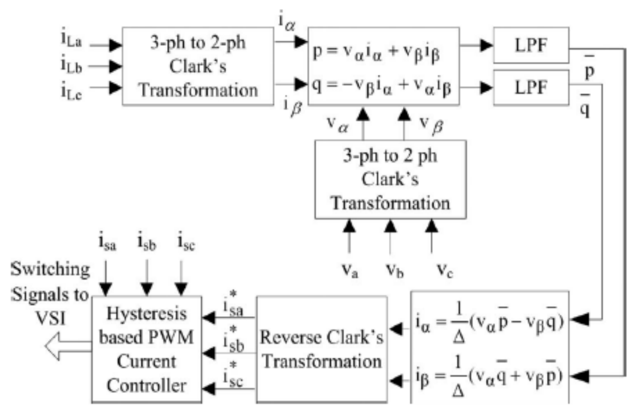

Fig. 3 Instantaneous P-Q theory

$$\begin{bmatrix} V_0 \\ V_\alpha \\ V_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_{Sa} \\ V_{Sb} \\ V_{Sc} \end{bmatrix} \qquad (2)$$

$$\begin{bmatrix} I_0 \\ I_\alpha \\ I_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} I_{La} \\ I_{Lb} \\ I_{Lc} \end{bmatrix} \qquad (3)$$

Equation (4) shows calculation of instantaneous real power (p), imaginary power (q) and zero sequence power ($p0$) components drawn by the load

$$\begin{bmatrix} P_0 \\ P \\ Q \end{bmatrix} = \begin{bmatrix} V_0 & 0 & 0 \\ 0 & V_\alpha & V_\beta \\ 0 & -V_\beta & V_\alpha \end{bmatrix} \begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} \qquad (4)$$

Where, $p = \bar{p} + \check{p}$ and $q = \bar{q} + \check{q}$

Where, the ˜ sign points to the alternating term and the - sign points to the direct component of each active and reactive power.The alternating term is the power ofthe harmonics of currents and voltages. For harmonic and reactive power compensation the direct and alternating components of the imaginary power ($\bar{q}$,$\breve{q}$ components) and harmonic component ($\breve{p}$) of the real power is selected as compensation power references and compensation current reference is calculated using equation (5). There will be no zero sequence power (*p0*) as the load is balanced.

$$\begin{bmatrix} i_{c\alpha}^{*} \\ i_{c\beta}^{*} \end{bmatrix} = \frac{1}{V_\alpha^2+V_\beta^2}\begin{bmatrix} V_\alpha & -V_\beta \\ V_\beta & V_\alpha \end{bmatrix}\begin{bmatrix} -\widetilde{p} \\ -\breve{q} \end{bmatrix} \tag{5}$$

The signal $\overline{p_{loss}}$is used as an average real power and is obtained from the voltage regulator. DC-link voltage regulator is designed to give both good compensation and an excellent transient response. The actual DC-link capacitor voltage is compared by a reference value and the error is processed in a proportional-integral (PI) controller, which is employed for the voltage control loop since it acts in order to minimize the steady-state error of the DC-link voltage to zero.

Equation (5) represents the required compensating current references ($i_{c\alpha}^{*}$, $i_{c\beta}^{*}$) in $\alpha-\beta$ coordinates to match the power demand of the load. Equation (6) is used to obtain the compensating phase currents (i_{CA}^{*} ,i_{CB}^{*},i_{CC}^{*}) in the *a–b–c* axis in terms of the compensating currents in the $\alpha-\beta$ coordinates:

$$\begin{bmatrix} i_{CA}^{*} \\ i_{CB}^{*} \\ i_{CC}^{*} \end{bmatrix} = \sqrt{\frac{2}{3}}\begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} i_{c\alpha}^{*} \\ i_{c\beta}^{*} \end{bmatrix} \tag{6}$$

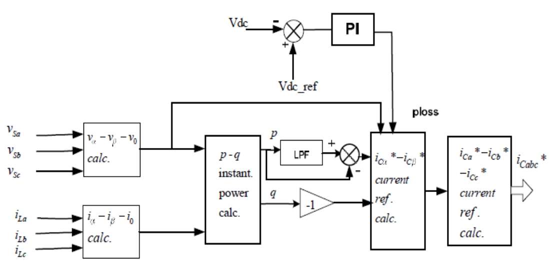

Fig.4 control scheme of shunt filter

5. Simulation Model & Results

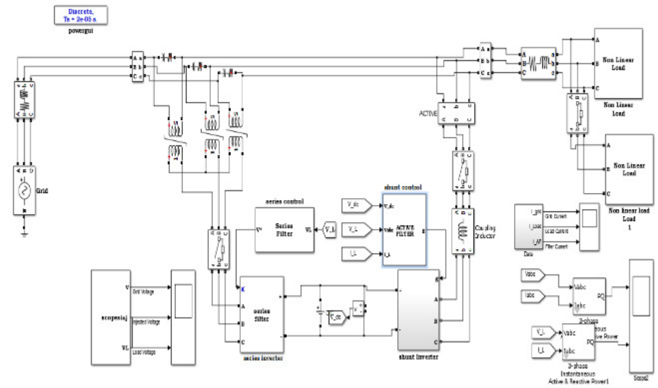

Fig. 5 simulation model of UPQC

The proposed control scheme is developed in MATLAB/SIMULINK environment. The specification and parameters in [3] used for the simulation purpose. Here we used three phase bridge rectifier with RL load as anon linear load. The simulation results of voltage sag, swell, voltage harmonics, voltage interruption and current harmonics are presented here.

5.1 Current and Voltage Harmonics Compensation

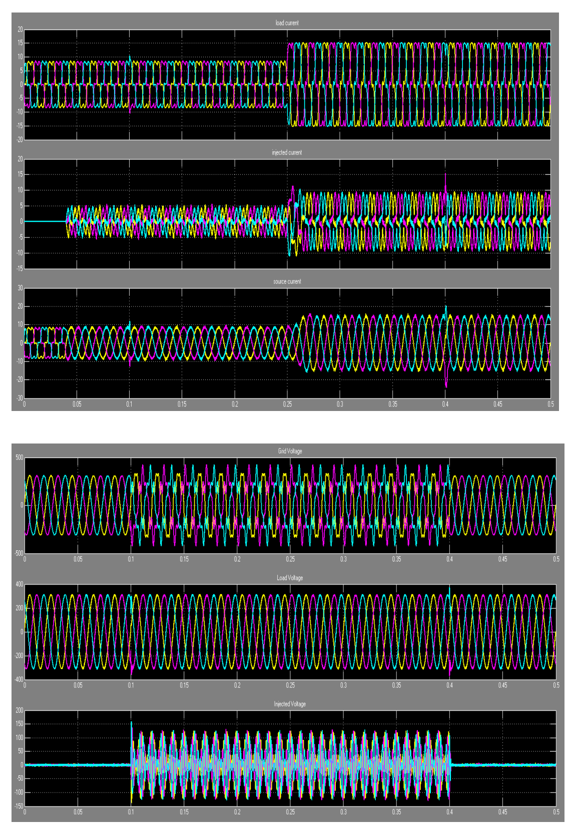

Fig.6 (a) load current (b) injected current (c) source current (d) source voltage (e) Load voltage (f) injected voltage

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Fig.6 shows the UPQC operation during voltage and current harmonic compensation simultaneously.It operate at 0.05 sec to compensate the harmonics. The shunt part of the UPQC injects the required current to make the source current sinusoidal. Due to the non-linear load there are harmonics present in the load current which can pollute the source current but with the help of the UPQC me maintain the supply current harmonics free, to check the capability of the UPQC we inject the 5th (20%) and 7th (20%) harmonics components during 0.1 sec to 0.4 sec. Here the series filter injects the compensating voltage out of phase voltage to compensate the load voltage. The series filter isolate the load side from the voltage harmonics. Fig. 7(a-b) shows the harmonic spectrum of the load current and source current. The load currents phase a signal shown here which consists harmonics, THD of the load current is 22.24% when we put the UPQC in operation then the source current THD reduce significantly by 4.72%. The arrangement here consists two non-linear load one of them put on at 0.25 sec, which introduce more harmonics into the system but the UPQC behaves very satisfactorily during this situation.

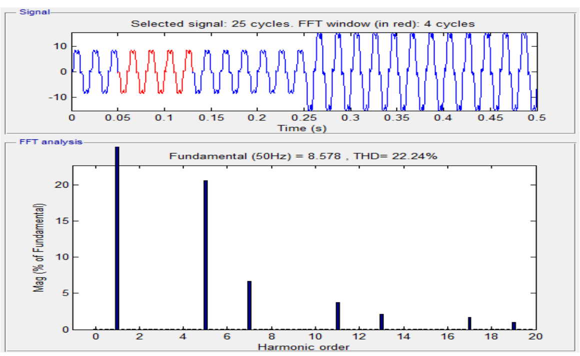


Fig. 7(a)

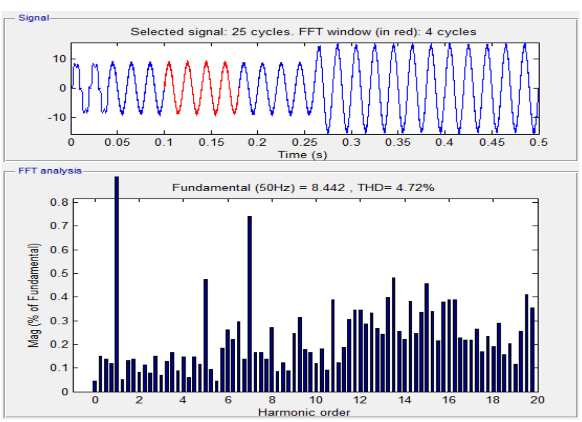


Fig. 7(b)

fig.8 (a-b) the harmonic spectrum of the source voltage and load voltage are shown here. Due to the injection of the 5th and 7th voltage harmonics the THD of source current is 28.39%. After the operation of the UPQC the load voltage become sinusoidal and the THD of load voltage reduce to 1.67% which considerably less.

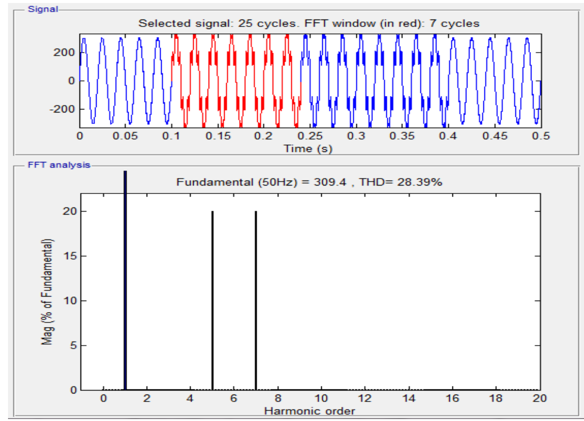


Fig. 8(a)

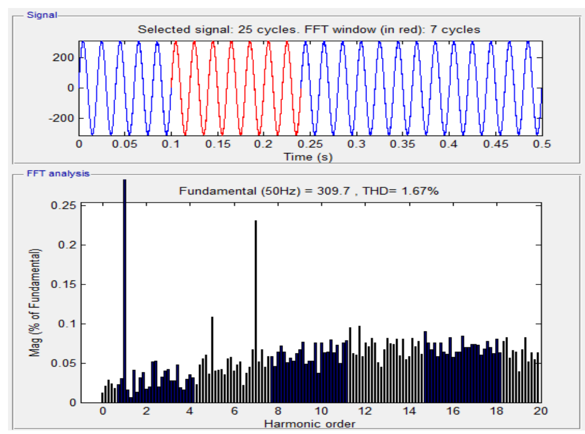
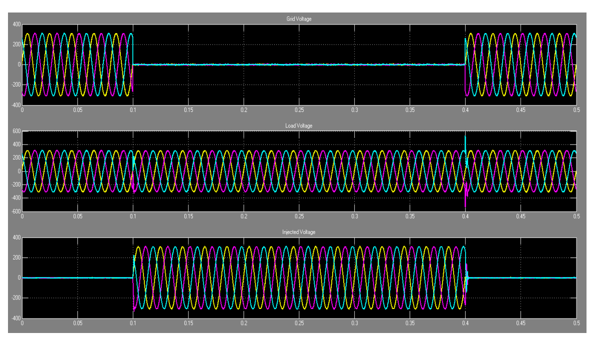


Fig. 8(b)

5.2 Voltage Interruption and Current Compensation



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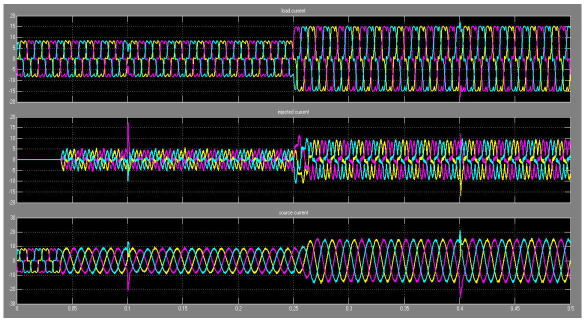
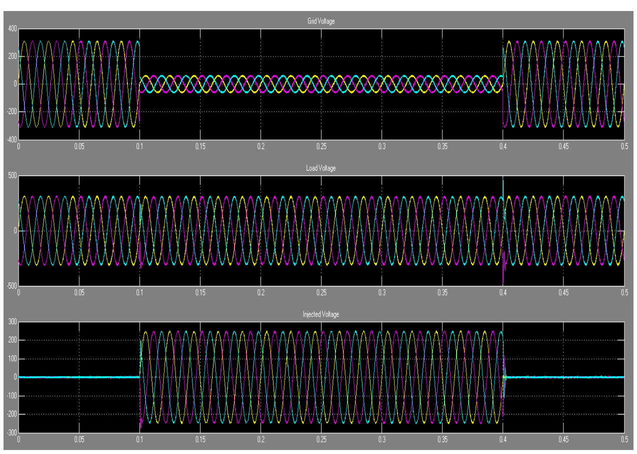


Fig. 9 (a) source voltage (b) load voltage (c) injected voltage (d) load current (e) injected current (f) source current

The simulation result of the voltage Interruption is shown here in Fig.9.The voltage interruption is introduced in the supply side during the 0.1sec to .4sec to analyse the capability of the UPQC. The series filter as soon as interruption occurs in the system it injects the voltage to compensate that interruption and maintain the load voltage uninterrupted. The power required by series filter to compensate that interruption supplied by the shunt filter through the DC link.

5.3 Voltage Sag and Current Harmonics Compensation

The simulation of Voltage sag is presented in Fig. 10 Here the sag induced in the supply voltage intentionally of .2 pu during the .1sec to .4sec. the series filter acts to improve the load voltage and injects the voltage in phase to supply voltage and maintain the load voltage at the normal value. The current compensation is also shown here simultaneously by the shunt filter at the same time, which shows the satisfactory work of the UPQC



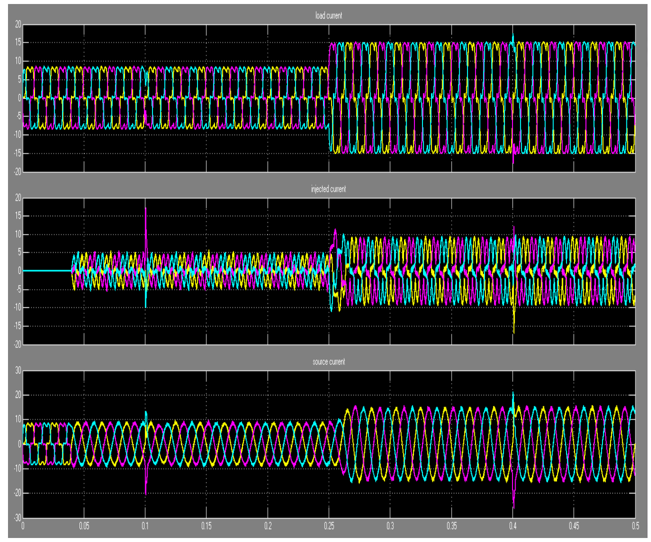
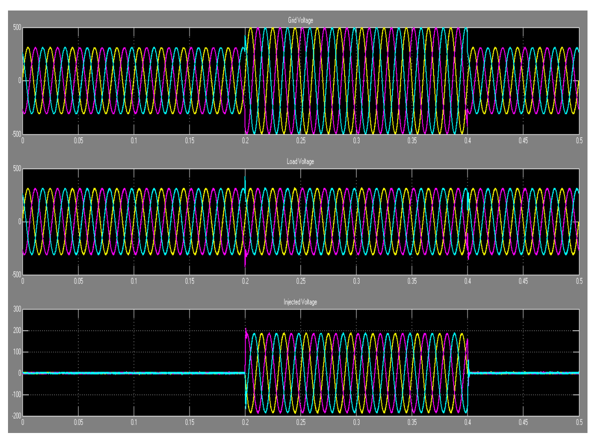


Fig.10: (a) source voltage (b) injected voltage (c) load voltage (d) load current (e) injected current (f) source current

5.4 Voltage Swell and Current Harmonic Compensation

Here we simulated the UPQC for voltage swell compensation in Fig.11. Swell induced here by the programmable supply of 1.6pu in the supply voltage during the .2sec to .4 sec. The series filter acts to compensate the swell induced and injects the compensated voltage which is out of phase with the source voltage and give the desired load voltage. The shunt filter here operate to compensate the load harmonics and maintain the source current sinusoidal.



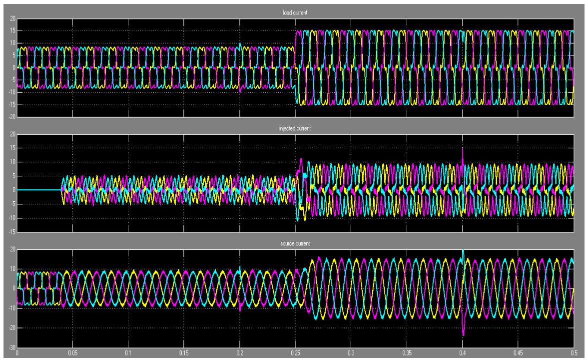


Fig.11 : (a) source voltage (b) injected voltage (c) load voltage (d) load current (e) injected current (f) source current

6. Conclusion

This paper proposes the control scheme for the UPQC operation using the UVT extraction for the series filter and instantaneous P-Q theory for the shunt filter reference signal generation. The results and simulation developed here in the MATLAB/SIMULINK environment. It can also shown here that all the power quality related problem can be taken care by that scheme. It can also observe here that the harmonics present in load side and the supply side below the IEEE 519 standard[8].

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